

2.0 SPACE STATION IMPACT EXPERIMENTS

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2.1 Introduction

The impact process is ubiquitous in the Solar System affecting planetary surfaces from the microscale (regolith evolution) to the megascale (planetary disruption). Over the last two decades research has largely focused on impact processes in which gravity plays a key role, whether in returning ejecta to the surface of the target body or in limiting crater growth. Ongoing research continues to provide fundamental new insights under such conditions. As earth-based observations and missions return new data about small bodies, however, we discover that our understanding of impact cratering under low-gravity conditions is severely limited not because of lack of interest but because of difficulty in removing this dominant variable in 1 g experiments. A Space Station Impact Facility would provide the unique opportunity to reproduce impact conditions unachievable on Earth and to explore parameters "masked" by the gravity term.

Four processes serve to illustrate potential areas of study and their implications for general problems in planetary science. *First*, accretional processes reflect the success of collisional aggregation over collisional destruction during the early history of the solar system. Asteroids and meteorites are relicts of this epoch, but many of the conditions leading to their formation and evolution cannot be achieved under terrestrial gravity conditions. *Second*, both catastrophic and less severe effects of impacts on planetary bodies surviving from the time of the early solar system may be expressed by asteroid/planetary spin rates, spin orientations, asteroid size distributions, and perhaps the origin of the Moon. Although theoretical models can be constructed to describe these collisional effects, they require both essential inputs and constraints that could be provided by experiments under low-gravity conditions. *Third*, the surfaces of planetary bodies directly record the effects of impacts in the form of craters; these records have wide-ranging implications. The size distribution of craters establishes the relative surface or resurfacing ages, and the morphology of craters provides clues to subsurface structure. The removal of the gravity term, however, results in craters much larger than those on a gravity-dominated surface, thereby modifying the recorded size distribution and the efficiency of crater destruction. Subtle forces may control final crater size and shape. Moreover, removal of the gravity term may help resolve fundamental issues for much larger craters on gravity-dominated bodies: for example, the origin of central peaks and the effect of gravity on the cratering flow field. Phobos, the Moon, and Mercury all have craters (basins) and antipodal patterns that may indicate near-destruction by a single event, but conditions favoring or limiting destruction remain poorly constrained. *Fourth*, regolith evolution of asteroidal surfaces is a consequence of cumulative impacts, but the absence of a significant gravity term may profoundly affect the retention of shocked fractions and agglutinate build-up, thereby biasing the correct interpretations of spectral reflectance data.

An impact facility on the Space Station would provide the controlled conditions necessary to explore such processes either through direct simulation of conditions or indirect simulation of certain parameters. The following discussion outlines a general plan for achieving this goal: 1) we propose a four-phased approach in implementing of both the facility and experimentation, 2) we review a tentative scenario for a Space Station Impact Facility with anticipated hardware requirements, 3) we identify possible commonality with other experiments, and 4) we offer recommendations.

2.2 Approach

A phased approach to microgravity impact experiments is necessary in order to refine specific experiment parameters and to gain practical experience. The subgroup identified four distinct phases: 1) Earth-based feasibility experiments; 2) STS (Shuttle) experiment package; 3) IOC (Space Station) experiment package; and 4) the Space Station impact facility. This phased approach will not only lead to further definition for the final goal--the Space Station Facility--but inevitably will also lead to new scientific results. Although the first three phases may be driven primarily by only a few research groups in order to maximize efficiency and minimize costs, an operational Space Station Impact Facility is envisioned as a national facility for a wide range of qualified users.

Earth-based Feasibility Studies

Constraints on the size of the impact chamber size restrict the range in micro-gravity experiments. Experience with existing low-gravity cratering data and extrapolations of data from higher g-levels indicate that crater dimensions and formation time increases dramatically under micro-gravity conditions. For example, at 1 g a 20-cm-diameter crater formed in a particulate target takes 0.2 seconds to form. If the current understanding of gravity effects is correct, then extrapolation indicates that at 0.001 g the crater will be 64 cm in diameter and take 10 seconds to form. The expected increase in crater size requires large containers; the increase in formation time would also permit numerous shock-wave reflections from container walls that could possibly affect crater growth. Consequently, the subgroup recognizes that initial experiments dealing with crater growth up through the IOC phase may be severely restricted and that the most promising results would first come from impact experiments focusing on free-floating targets. Further experience is needed, however, in order to assess the severity of such constraints and to identify the crucial parameters for specific IOC experiments. Such experience can only be gained from properly designed experiments at existing facilities (e.g., NASA-Ames Vertical Gun and Johnson Space Center Vertical Impact Facility) and exploratory low-gravity experiments at the Ames facility, the KC-135 Reduced Gravity Aircraft, and drop-towers. The latter two facilities also provide essential experience with target design, preparation, and design of the IOC Impact Facility.

STS Impact Experiment Package

This phase offers proof-of-concept and design resulting from earth-based feasibility studies. The subgroup recognized enormous benefits that would accrue from experience on the Space Shuttle. This experience includes

problems in target preparation and handling (e.g., construction of particulate spheres, free-floating liquid targets) and in testing preliminary designs of the IOC package.

IOC Impact Experiment Package

The first phase of Space Station experiments most likely will concentrate on impacts of free-floating targets in order to better understand phenomena associated with collision processes. The subgroup presently envisions this facility to be equipped with an accelerator permitting impact velocities from 0.1 to at least 2.5 km/s, monitoring systems (launch diagnostics, film/video records, etc.), and an ability to prepare, analyze, and exchange targets. The IOC module will be a direct outgrowth of the STS package but with increased sophistication to anticipate requirements for a larger impact chamber and to ensure meaningful scientific results. An impact chamber size of at least 1.0 m³ is required.

Space Station Impact Facility

Key requirements for this final operational phase include variable gravity levels (10^{-5} g to 0.2 g), a large impact chamber (4 m diameter minimum), full range of impact velocities (0.1 km/s to at least 6 km/s), variety of targets (particulate, liquid), and experimenter interaction. More specific requirements and descriptions are deferred to a subsequent section. The expanded dimensions and capabilities permit systematic analyses of crater scaling, crater flow fields, crater relaxation, regolith evolution, accretion studies, and more elaborate free-floating targets.

2.3 Space Station Impact Facility: A Scenario and Requirements

In order to visualize the ultimate configuration of this facility and to identify problem areas, a tentative scenario with hardware requirements was compiled. The reader is reminded that this is a *preliminary* view that will evolve with further experiments and experience gleaned from the phased approach. Five key requirements, however, have emerged: 1) variable g, 2) large impact chamber, 3) wide range in impact velocities, 4) flexibility in target composition and structure, and 5) "hands-on" experiment operation.

Impact Chamber

A large chamber is necessary in order to reduce reflections of shock waves from the walls of the target container, to contain/capture ejecta products, and to ensure a variety of more complex free-floating targets. A minimum chamber size of 4 m by 4 m by 4 m is envisioned. In early stages of implementation this might be achieved within the primary module; nevertheless, the subgroup strongly urges the availability of airlocks at least 1 m in diameter in order to accommodate an add-on chamber of larger size and an accelerator mount. We suggest that airlocks on opposite sides of the module be considered in order to anticipate possible extensions for advanced accelerator designs. It is virtually certain that the desired variation in gravity levels will be obtained through some application of centrifugal force. The geometry that would yield the lowest rotation rate--presenting the smallest induced Coriolis effects--would find the target chamber at one end of a free-floating habitable module. On the other hand, other arrangements might

be more desirable. A set-up that would find the chamber and accelerator attached to the two airlocks or docking ports, for instance, might be handled better by spinning the module along its major axis, i.e., perpendicular to the axis running through the chamber and accelerator. The chamber should be capable of operating in conditions ranging from vacuum to ambient atmospheric levels. It is possible that the Impact Chamber would be used also as a target preparation area. The large size of this chamber may be useful for other experimenter groups.

Accelerators

In order to achieve the desired range in impact velocities (0.1 to 7 km/s), the subgroup presently envisions the use of light-gas gun, powder-gun, and air-gun technology. Light-gas gun technology has been used for over thirty years and could be adapted easily. The subgroup also recognizes, however, that new technological advances in rail guns, mass drivers, and electrothermal guns may provide feasible alternatives and must not be designed-out. Additionally, experiments involving low-yield explosives will be desired. Post experimental analysis envisions the need for holographic systems, binocular microscopes, still photography, mass determination, and sample curating. The subgroup envisions real-time telemetry of experimental data to the earth for analysis by ground-based personnel.

Instrumentation

Three primary groups of instrumentation support are envisioned: launch/environment diagnostics, impact recording instrumentation, and post-impact analytic diagnostics. Launch/environment diagnostic instrumentation includes computer-controlled gun operations/sequencer, projectile velocity, sequencer, flash x-ray generators and detectors, pressure and temperature transducers, and accelerometers. This instrumentation is necessary to record projectile velocity and integrity, to monitor conditions at impact, and to coordinate instrumentation and sequence of use. Impact recording instrumentation includes a range of film recording devices from 24 fps to 35,000 fps (movie and video), lighting, pressure transducers, ejecta sensors, computer-controlled 20 channel digital transient recorder, and holographic recording. Several experimental recording instruments will be integrally tied into micro-computers, and we envision that one of these will be used to program experimental theories and backup for each mission.

Target Preparation and Housekeeping

An assortment of additional requirements include target containers, molds, sieves, vacuum systems, target preparation equipment, small lathe and other power tools, "scales" for mass determination, microwave heater, transducers, ice-crusher/freezer, oven, and miscellaneous "furniture" (benches and accessories). We envision such materials to be needed by other experimenters and anticipate a mutually shared facility.

Personnel

In this advanced experimentation phase, we recognize the need for 2 payload specialists and 2 back-up specialists on the ground.

2.4 Summary

It must be emphasized that this scenario depicts a fully operating facility more than a decade in the future. Such an exercise was performed in order to envision more limited needs and requirements during earlier phases and to anticipate design requirements at much later phases.

Commonality

The large impact chamber, certain recording instrumentation (video, film recorders, microcomputer, etc.), and shop facilities all should be conducive to shared-use with other experiment groups, although not necessarily at the same time. The unique section of this facility is primarily the accelerator system; however, proper design should permit portability. It is possible that the accelerator system, however, may be useful for certain studies in shock dynamics (shock tube) in addition to the more typical impact experiments.

2.5 Recommendations

The Impact Experiment Subgroup recommends a phased approach in order to gain insight and experience with impact processes under low to micro-gravity conditions. This phased approach includes pilot studies and research involving existing impact facilities, the KC-135 Reduced Gravity Aircraft, and drop-towers. The subgroup feels that the most useful first experiments at micro-gravity (IOC) will involve impacts of free-floating targets in order to understand the effects of momentum transfer and disruption on realistic or modeled planetary bodies (e.g., regolith-covered bodies, fluid spheres, etc.). However, continued studies may identify additional configurations during the IOC phase.

The subgroup also recommends that additional studies involving meteorite impact detectors and cosmic dust collectors be encouraged since the results of such studies will be complementary.